DAM SAFETY ASSURANCE PROGRAM
EVALUATION REPORT AND
ENVIRONMENTAL IMPACT STATEMENT

APPENDIX C – TAB I
HYDROLOGY AND HYDRAULICS

DOVER DAM, OHIO
TUSCARAWAS RIVER

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ANNEX C-1-1
Hydraulic Profiles

This TAB (I) of the Engineering Appendix (C) presents and discusses hydrologic and hydraulic data and analyses that were performed for the Dam Safety Assurance (DSA) Evaluation Report for Dover Dam. Inflow flood hydrographs were developed, flood routings were performed, water surface profiles were computed for the Tuscarawas and Muskingum Rivers and pertinent tributaries.

The results of the hydrologic and hydraulic analyses were used by other Huntington District office personnel to determine population at risk (PAR) and economic damages for an array of flood events for both "with" and "without" dam failure scenarios. These two parameters are significant factors in determining the downstream hazard, which in turn factors in to the decision process to determine whether to upgrade the existing dam to comply with modern day design criteria or breach and abandon the dam.

As the potential for loss of life during a dam break scenario is heavily dependent on the hydraulic characteristics of the associated river valley, the methodology and results of the calculations for the potential for loss of life is also presented in this TAB.

EXISTING PROJECT DESCRIPTION

1.1. General. Dover Dam is located in Tuscarawas County, Ohio, on the Tuscarawas River a tributary of the Muskingum River, approximately 3.5 miles upstream from Dover, Ohio, and 4 miles northeast of New Philadelphia, as shown in the Figure 1 of the main report. The dam site is located approximately 173.6 miles above the confluence of the Muskingum River with the Ohio River. Dover Dam is a concrete gravity type flood control structure founded on limestone and silt shale. An uncontrolled overflow ogee type spillway is located in the channel section of the dam. Total reservoir capacity is 203,700 acre feet at maximum flood control pool elevation of 916.0, which is equivalent to approximately 4.9 inches of runoff. Dover Dam is a dry dam, and does not retain a permanent pool.

Three other Corps of Engineers flood control reservoirs are located upstream of Dover Dam on tributaries of the Tuscarawas River. Dover Dam controls a drainage area of 1397 mi^2. Of that total drainage area, Bolivar Dam controls 502 mi^2, Atwood Lake controls 70 mi^2, and Leesville Lake controls 48 mi^2, leaving 777 mi^2 to be controlled solely by Dover Dam.

1.2. Dam. The Dover dam is a concrete structure with an overall top length of the dam is 824 feet at elevation 931.5. The maximum height of the dam is 83 feet. Keywalls extend 20 feet into bedrock over most of the length of the dam, except for two monoliths, where the entire monolith foundation was lowered 20 feet because of a fault and severely fractured limestone discovered during construction. A grout curtain extends below the keywall and foundation drains extend from the foundation to the drainage gallery. The embankment slopes are 2 horizontal to 1 vertical (2:1).

1.3 Spillway. It is an uncontrolled ogee type spillway with a crest width of 338 feet at elevation 916.0. The spillway outlet channel is concrete lined for 180 feet downstream of the crest. The original design discharge is 123,200 cfs with a surcharge of 20.8 feet and a freeboard of 2 feet.

1.4 Outlet Works. The outlet works consist of 18 gated sluices through the spillway section of the dam. These sluices are arranged in groups of six, with each group having different invert elevations. The lowest group is on the right, looking downstream, with the sluice inverts at elevation 862 and the sluices controlled by 5' x 10' slide gates. The next higher group is on the left, where the sluices are controlled by 7' x 7' slide gates and the invert elevation is 867. These sluice inverts for the central group are at the elevation 872. These sluices are also controlled by 7' x 7' slide gates.

The outlet works discharge into a stilling basin, which is also separated by partial dividing walls into three sections corresponding to the three groups of sluices. The right section is at elevation 854, the left at elevation 860, and the central section at elevation 859. Each section has a series of baffle blocks and the two lower sections have an end sill which extents to elevation 860.

1.5. Watershed Characteristics

1.5.1 Topography. The Tuscarawas River is the main stream in the Dover Dam drainage basin. It flows in a general southwest direction from its headwaters to the dam site. From its source at approximately elevation 1000 ft. to the dam area at elevation 858, the Tuscarawas River has a total fall of 280 feet in a distance of about 80 miles.

Tuscarawas River Valley is a broad, flat bottomed topographic feature with rather steep walls and rolling hills, well dissected, upland country whose general elevation ranges from 600 to 900 feet above mean sea level. In this valley the Tuscarawas River follows a meandering course flanked by broad flood plains. In some areas, the bottom width of the valley is a half mile or more. At the Dover dam site, the valley narrows to approximately 2500 feet. The general elevation in the valley bottom at the site is 858 feet above mean sea level. The bottom width along the axis of the dam site is about 950 feet.

The topography of Tuscarawas County has been produced almost exclusively by erosion. From the study of its geology, it is learned that the surface originally formed a plain on the southern slope of the watershed, having a gentle inclination toward the south, in the lapse of ages, the plain has been deeply furrowed by the great line of drainage which traversed it, now known as the Tuscarawas River. The valley of this stream was originally cut to the depth of more than 700 feet below the highest lands of the county, and, though partially filled, it still exists as a broad and deep trough, more than 300 feet below the adjacent highlands. The tributaries of the Tuscarawas are quite numerous, and some of them are of considerable size, such as Sugar, Conotten and Stillwater Creeks, and all of these, having deeply excavated their channels, has formed a network of valleys, which give great diversity to most of the surface. The relief or relative elevation of some portions of the county may be plainly seen by one, who, starting from New Philadelphia will pass to a distance of ten miles either east or west.

The town of New Philadelphia is located on a floodplain terrace, which reaches northward to Dover, and has an elevation of forty to fifty feet above the bed of the Tuscarawas River. This plateau is the old flood plain of the river, formed when it ran at a higher level than now. It is composed of gravel, as is shown by borings, and is the surface of the mass of drift that occupies the bottom of the old excavated valley. At Dover, the borings made for salt have shown that the rock bottom of the valley lies 175 feet below the present surface of the Tuscarawas. Hence the plains between Dover and New Philadelphia are underlain by 200 feet of sand, gravel and boulders, which have been filled into the old valley since the remote period when the continent stood higher.

1.5.2 Precipitation Characteristics. Northeast Ohio has a climate essentially continental in nature, characterized by moderate extremes of heat and cold, and wetness and dryness. It is in the path of rain-producing storms that move across the nation in a general west-to-east direction. The storms often converge in the Great Lakes region and leave by way of the St. Lawrence River Valley. The southern half of the state is visited more frequently by productive rainstorms. The lifting of moist air masses over the hilly terrain tends to increase the yield of rainfall, especially in winter and spring. Extreme amounts of precipitation and long periods of drought are relatively uncommon.

Precipitation data is recorded at Dover Dam and also at Middlebourne and Barnesville outside of the basin. Normal annual precipitation at Dover Dam is 37.10 inches, with monthly normal precipitation ranging from 2.29 inches in February to 4.29 inches in July. Annual precipitation values at the Middlebourne and Barnesville stations are 35.10 inches, and 41.47 inches, respectively. Snowfall data has not been recorded in the Dover Dam basin, but data is available at Barnesville. Based on data from 1958 through 1985, the average annual snowfall at Barnesville is 35.6 inches.

1.5.3 Flood Characteristics. Most floods in Ohio are caused by precipitation of unusual intensity or of unusual duration and extent. Floods may also result from a series of ordinary storms which follow one another in rapid succession or from rain falling at relatively high temperatures on snow-covered areas. At times, though infrequently, flood conditions are caused or aggravated by ice jams, especially in the tributary streams. Severe thunderstorms frequently cause local flash flooding. General flooding in the basin occurs most frequently during the winter or early spring months, but it can occur at any time during the year.

1.5.4 Storms and Floods

1.5.4.1. Storm and Flood of March 1913. The storm causing this flood was generally over the northern half of the Ohio River Basin, with the heaviest precipitation in the states of Indiana and Ohio. The main storm event was preceded by rainfall of 1.0-1.5 inches that occurred on 20 and 21 March throughout the Ohio Valley and thoroughly saturated the ground. Then, an unusually large percentage of subsequent heavy rain during the main storm event, on 23 to 27 March, produced rapid runoff. All flood records on the southerly flowing tributaries of the Ohio River in Ohio and Indiana were broken.

In the Muskingum River Basin, the rain storm commenced just before noon on 23 March, with the rain becoming increasingly heavy for the next two days. Rain continued on the 26th and in some portions of the basin also continued on the 27th. The total rainfall during the five days, most of which occurred in a period of 96 hours or less at individual points, averaged 6.55 inches over the Tuscarawas River Basin. No rainfall measurements are available within the Dover Dam basin, but at Cadiz, total rainfall for the 5-day period was 5.67 inches. As a result of the exceedingly heavy rain falling on ground that was already saturated by antecedent precipitation, the maximum floods of record occurred on practically all major streams in the Muskingum River Basin. Main streams rose to unprecedented heights. The March 1913 flood caused the loss of 367 lives and damages amounting to $14.0 million (1913 dollars) in the Muskingum River Basin.

1.5.4.2. Storm and Flood of August 1935. The storm which produced the flood of 6-7 August 1935 was one of the largest general summer floods to occur in the Muskingum River Basin. Streams levels measured raised and soil retention capacities were minimized due to heavy local showers which occurred in the basin between 31 July and 4 August. As a result, the intense rains that followed on 6-7 August produced large volumes of runoff in the watershed. Rainfall for the storm averaged 4.1 inches over the entire Muskingum River Basin, with more than 8 inches falling over a 400 square-mile area in the central portion of the basin, and more than 12 inches being recorded near Newcomerstown. This storm produced the highest summer stages of record on the Tuscarawas River below Dover, and on the main stem of the Muskingum River.

1.5.4.3. Storm and Flood of January 1937. A series of abnormally heavy rains in late December 1936 and most of January 1937 caused a major series of floods in the middle and lower portions of the Ohio River Valley. Tributary streams in the Tuscarawas River Basin experienced successions of flood increases that moved out of the smaller rivers to accumulate in the larger rivers. This resulted in increasingly higher stages and discharges after each storm. The heavy general rainfall continued intermittently for almost an entire month. This series concluded with the heaviest storm from 14 to 25 January in which 7.93 inches fell over the Muskingum River Basin. The partially completed flood control reservoirs decreased the peak stages and discharges by acting as retarding basins.

1.5.4.4. Storm and Flood of January 1959. The storm and flood of January 1959 are generally regarded as one of the highest of record throughout most sections of the Tuscarawas River Basin. The conditions prior to the generalized rains on 20 and 21 January contributed greatly to the flood stages throughout the basin. Severe cold weather during December 1958 froze the ground to depths ranging from 6 to 18 inches. In addition, a storm occurring between 14 and 17 January deposited from 0.50 to 1.84 inches of precipitation over the basin. Thus, the ground was saturated, frozen, and covered with varying amounts of snow. This combination contributed significantly to the high percentage of runoff encountered after the generalized rain began. Most of the flood producing rains fell between midnight on 20 January and noon on 21 January. Only 1.22 inches of rain fell at the Dover Dam, but an isohyetal map of the storm indicates that more than 2 inches of rain fell in the upper portions of the Dover Dam watershed.

1.5.4.5. Storm and Flood of July 1969. On the evening of 4 July 1969, severe thunderstorms with intense rainfall moved across northern Ohio. The storm was centered along a line from east of Toledo through Ashland and Wooster to Uhrichsville. The average rainfall over the Muskingum River Basin upstream of Coshocton was 6.6 inches for the 18-hour period ending at 1:30 p.m. on 5 July. Unofficial measurements ranged from 10-14 inches for the same period in the Wooster area. Total rainfall for the storm at the Dover Dam was 3.5 inches. This intense rainfall and runoff resulted in the rapid and severe flooding of much of the upper Muskingum River Basin. However, the Dover Dam drainage basin was not significantly affected by the storm. It is estimated that operation of the Tuscarawas River basin dams reduced flood stages at Tippecanoe and Uhrichsville by less than 2 feet.

1.5.4.6. Storm and Flood of February 1979. Antecedent conditions prior to moderate rainfalls near the end of February 1979 were predominantly responsible for flooding conditions in the basin. Soils were frozen and a snow cover persisted over most of the Muskingum River Basin from early January to the onset of the major rainfall on 25-26 February. Snow cover on the basin ranged from approximately 6 inches in the northern part of the basin to 20 inches at McConnelsville. Based on data from Dover Dam and Barnesville, snow cover on the Dover Dam basin was estimated to be about 12 inches. Temperatures rose above freezing for the first time in nearly 4 weeks on 20 February and, combined with rainfalls of less than 0.5 inch on 21-22 February, created rapid melting of snow and runoff and rising stages along the basin's streams. Continued thawing combined with heavier rainfalls of approximately 1.5 inches over the basin on 25-26 February produced heavy runoff and considerable flooding in the Muskingum River Basin. Rainfall at Dover Dam for the period was 1.60 inches.

1.5.4.7. Storm and Flood of August 1980. Heavy rainfall on saturated ground was primarily responsible for the flooding conditions experienced by many portions of the Muskingum River Basin in August 1980. Basin rainfalls averaged approximately 150% of normal during June and July 1980. Widespread, intense thunderstorms produced the bulk of the basin's precipitation in August, with a large portion of the basin receiving more than 10 inches of rain during the month. Dover Dam received 10.65 inches of rain in August. Heavy rainfalls, at times exceeding 1-2 inches were common throughout most of the Muskingum River Basin during storms of 2-6 August, 9-12 August, 17-19 August, and 21-22 August. The most notable storm in the Muskingum River Basin occurred on 10-11 August in Guernsey, Belmont, Licking, and Muskingum Counties. The Cambridge area received nearly 8 inches of rain in about 18 hours, and most stations in these counties received at least 3.5 inches of rain from the storm. The recording station at Dover Dam (at the northern end of the watershed) received 3.81 inches of rain, but Barnesville, located just south of the upper end of the basin received 5.91 inches of rain from the storm. Wills Creek at Cambridge reached its highest peak since 1935, and the combination of August storms produced the highest pool of record at Dover Dam. Operation of the Muskingum River Basin dams reduced flood stages significantly during the month, especially downstream of Wills Creek Dam and Dillon Dam after the storm of 10-11 August.

1.5.4.8. Storm and Flood of January 2005. Heavy rainfall on saturated ground was primarily responsible for the flooding conditions experienced by many portions of the Muskingum River Basin. Around 23 December 2004, rainfall of 1 to 2 inches preceded a snow fall of 2 inches to 5 inches. Temperatures remained below normal until the week after December 25, 2004 at which time temperatures were on the rise and snowmelt began saturating the soils. Approximately 4 to 8 inches of rain fell through much of the watershed over an eleven-day period and combined with melting snow, led to large amounts of runoff that eventually flowed directly into the streams where dams are located. New record pools were established at Atwood, Bolivar, Charles Mill, Dillon, Dover, Mohawk and Wills Creek reservoirs. Nearly all of the other reservoirs reached their crests between Jan. 14-20. While Wills Creek reached its designed storage capacity before cresting and Beach City nearly reached its capacity, all of the other projects had additional storage capacity remaining when they crested.

2. SPILLWAY DESIGN DEFICIENCY

2.1 Original Spillway Design Criteria. When the Dover project was designed, regional estimates of probable maximum rainfall had not been established. For spillway design purposes, the inflow hydrograph used in the original design of the Dover Dam spillway was developed from plots of peak flows and total storm runoff in inches versus drainage area for the 1913 flood in the Miami River Basin.

2.2 Present-Day Probable Maximum Precipitation Estimates. Since the construction of Dover Dam, the National Weather Service (NWS) has developed generalized estimates of Probable Maximum Precipitation (PMP) for areas of the United States east of the 105th meridian. These PMP estimates were published in Hydrometeorological Report (HMR) No. 33 dated 1956, but were limited to areas of 1,000 square miles or less. Revised and expanded PMP estimates by the NWS were later published in HMR No. 51 dated June 1978, covering areas up to 20,000 square miles.

2.2.1 Probable Maximum Precipitation. PMP calculations for the eastern United States are based on the procedures and data given in HMR No. 51 and HMR No. 52. HMR No. 51 provides estimates of area-averaged PMP for the United States east of the 105th meridian. HMR No. 52 provides a procedure for obtaining drainage area averaged PMP amounts from the storm area averaged PMP given in HMR No. 51. This procedure determines isohyetal values for up to twelve 6-hour periods for an elliptical precipitation pattern. Included in the technique are adjustments for both basin shape and effects of storm pattern orientation. PMP, infiltration, and rainfall excess estimates for the area upstream of Dover Dam are shown in Table 1.

2.2.2 Probable Maximum Flood (PMF) Hydrographs. A previous evaluation of the PMF at Dover determined the “C” hydrograph is appropriate for use in the hydrologic analysis and design. Therefore, the current hydrologic investigations utilize the “C” hydrographs at the project sites for pool routing. The “C” hydrograph represents a 150% increase in the unit hydrograph inflow peak with the proper volume adjustment on the drainage area above the pool. Unit hydrographs for the drainage area adjacent to the lake, drainage area above the pool and the lake surface were also applied to the PMP.

These local hydrographs were then routed and combined in accordance with EM-1110-2-1405 to derive the final project "C" hydrographs shown on Figures 1, 2, 3 and 4. The application of the PMP to the 6-hour unit hydrographs and the routing of the resulting local hydrographs were developed by using the HEC-HMS computer program.

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Table 1
Probable Maximum Rainfall
For Dover Dam Drainage Area

PROBABLE MAXIMUM RAINFALL												
	BOLIVAR DAM			LEESVILLE LAKE			DOVER UNCONTROLLED			ATWOOD LAKE		
6-HOUR Period, No.	Rainfall (Inches)	Loss (Inches)	Rainfall Excess (Inches)	Rainfall (Inches)	Loss (Inches)	Rainfall Excess (Inches)	Rainfall (Inches)	Loss (Inches)	Rainfall Excess (Inches)	Rainfall (Inches)	Loss (Inches)	Rainfall Excess (Inches)
1	0.29	0.29	0.00	0.28	0.28	0.00	0.27	0.27	0.00	0.31	0.31	0.00
2	0.35	0.35	0.00	0.34	0.34	0.00	0.33	0.33	0.00	0.37	0.37	0.00
3	0.44	0.36	0.08	0.43	0.41	0.02	0.42	0.41	0.01	0.48	0.42	0.06
4	0.61	0.30	0.31	0.60	0.30	0.30	0.58	0.30	0.28	0.66	0.30	0.36
5	0.99	0.30	0.69	0.96	0.30	0.66	0.94	0.30	0.64	1.06	0.30	0.76
6	2.57	0.30	2.27	2.37	0.30	2.07	2.36	0.30	2.06	2.70	0.30	2.40
7	11.57	0.30	11.27	9.32	0.30	9.02	9.69	0.30	9.39	11.75	0.30	11.45
8	1.43	0.30	1.13	1.38	0.30	1.08	1.35	0.30	1.05	1.52	0.30	1.22
9	0.75	0.30	0.45	0.73	0.30	0.43	0.72	0.30	0.42	0.81	0.30	0.51
10	0.51	0.30	0.21	0.50	0.30	0.20	0.49	0.30	0.19	0.55	0.30	0.25
11	0.39	0.30	0.09	0.38	0.30	0.08	0.37	0.30	0.07	0.42	0.30	0.12
12	0.31	0.30	0.01	0.31	0.30	0.01	0.30	0.30	0.00	0.34	0.30	0.04
TOTAL:	20.21	3.70	16.51	17.60	3.73	13.87	17.82	3.71	14.11	20.97	3.80	17.17

The “2” hydrograph is the drainage area around the pool. The “3” hydrograph is the surface area of the pool. The “1-C” hydrograph is the drainage area upstream of the pool. The PMP is applied directly to the lake surface without any initial loss or infiltration rate, and the drainage area between the dam and the beginning of the upstream area with appropriate losses. These local hydrographs were then routed and combined in accordance with EM-1110-2-1405 to derive the final project "C" hydrographs shown on Figures 1, 2, 3 and 4. The application of the PMP to the 6-hour unit hydrographs and the routing of the resulting local hydrographs were developed by using the HEC-HMS computer program.

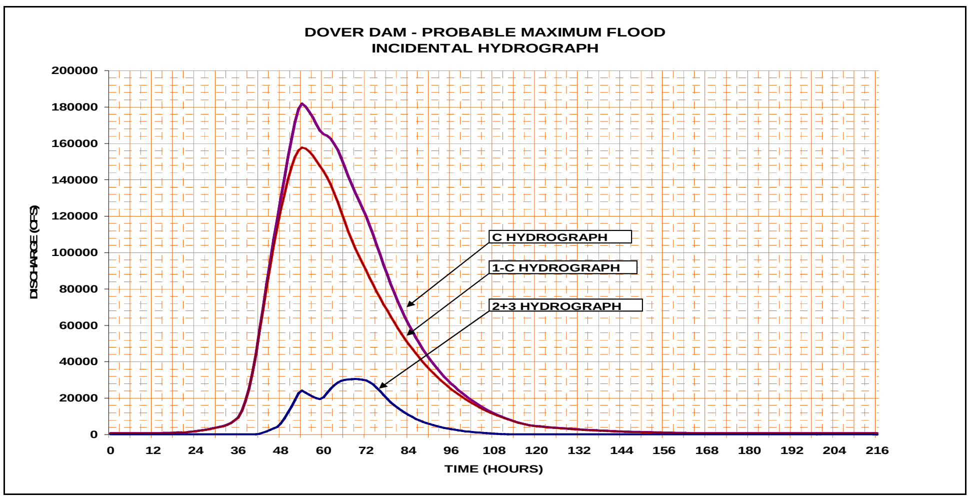

Figure 1 (Dover Dam Probable Maximum Flood Incidental Hydrograph)

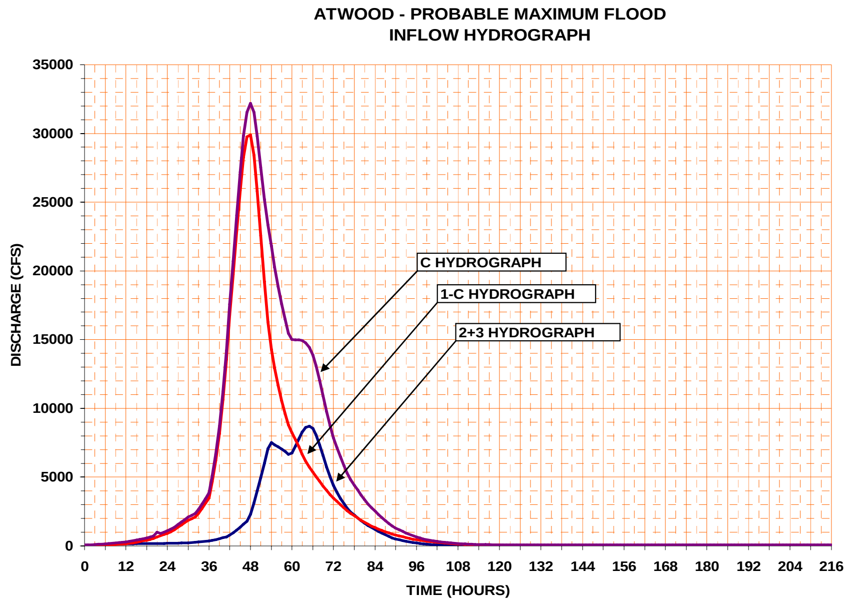

Figure 2 (Atwood Lake Probable Maximum Flood Hydrograph)

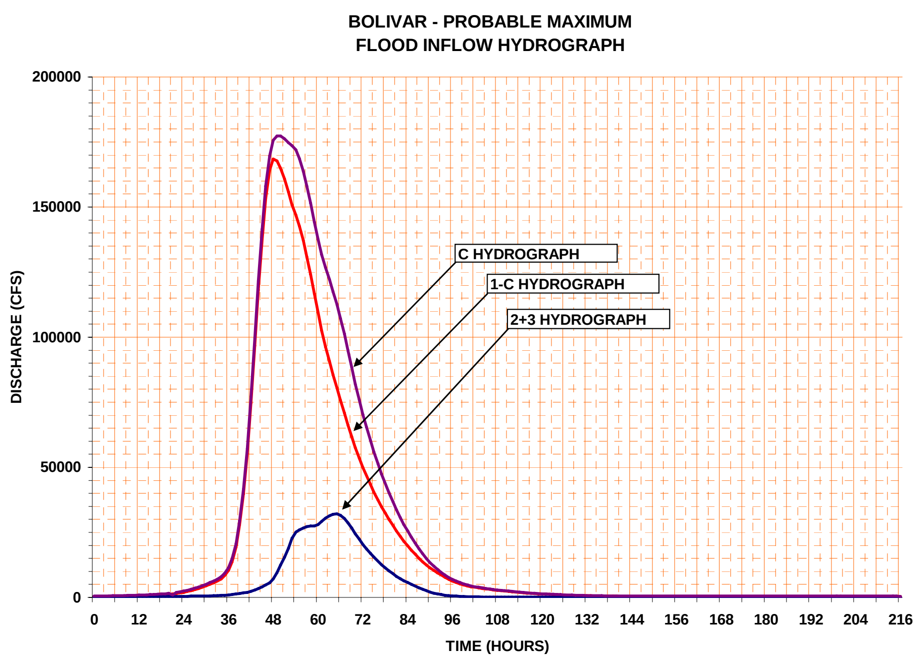

Figure 3 (Bolivar Dam Probable Maximum Flood Hydrograph)

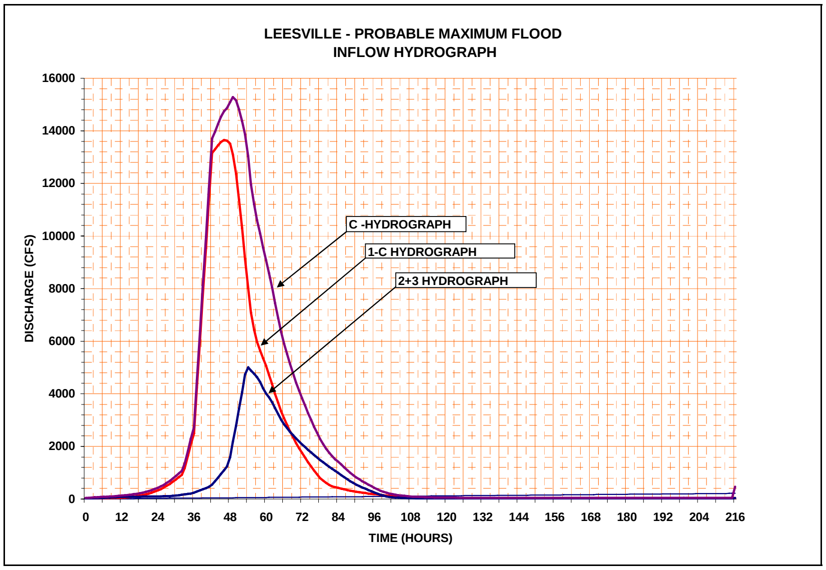

Figure 4 (Leesville Lake Probable Maximum Flood Hydrograph)

2.3 Reservoir Regulation Plan Assumed in Flood Routing. The revised Probable Maximum Flood and Lesser Floods were routed through the existing spillway and outlet works according to the “Dover Dam - Project Manual for Water Control Management”, Section 7, "Water Control Plan" and Annex I, "Instructions to Project Supervisor".

The Tuscarawas River is controlled through the optimal use of storage capacity at Dover Dam, Bolivar Dam, Atwood Lake and Leesville Lake. The outflow from these lakes is normally regulated to maintain no-damage flows at the control gages on Tuscarawas River located at Dover Dam, New Philadelphia, and Newcomerstown, Ohio and on Muskingum River at Coshocton, Dresden, Zanesville, McConnelsville and Marietta, Ohio. During normal reservoir operations, the discharge from Dover Dam is controlled so that the no-damage stage on the outflow gage is not exceeded. During the period from middle of April through November this stage is 6.5 feet, and during the period from December to the middle of April this stage is 7.5 feet.

For a major flood, the water control plan provides for increases in reservoir outflow when there are indications that available storage will be insufficient to completely control the flood. Any surcharge storage at Dover Dam would result in flood damage to property in the reservoir area, since the taking line for the acquisition of lands within the Dover Reservoir is at spillway crest elevation 916.0. Since the storage capacity of Dover Reservoir is limited to 4.9 inches, it is proposed to operate the reservoir to prevent the pool from exceeding the spillway elevation of 916.0.

During a flood of the magnitude considered in this Dam Safety Assurance study, dam safety would be of prime concern and all available discharge facilities would be operated to preclude dam overtopping. Since the outlet works gates are functioning properly at Dover Dam, there is nothing to indicate that the project cannot operate at full discharge capacity during major flood events. Therefore, the spillway and outlet works were assumed to have the capability to operate at 100 percent capacity during the events considered in this study.

2.4 Existing Spillway and Outlet Works Ratings. Ratings for the existing outlet works ratings incorporate reductions for high tailwater conditions produced by spillway flow. However, neither the outlet works nor spillway rating extended as high as the pool levels that required analysis in this study. Therefore, it was necessary to extend both the spillway and the outlet works rating curves to the elevations of the pool levels that are presented in this report.

2.5 PMF Routing Results. The PMF was routed using Reservoir Simulation (HECResSim) and HEC-RAS, as developed by the Hydrologic Engineering Center, Davis, California, to simulate or model the authorized basinwide reservoir operation plan. A HECResSim and HEC-RAS computer models description is more broadly described in Section 5.1. By routing the controlling antecedent flood event equivalent to 39% of the PMF, with a five day dry period, the pool level at 192 hours was determined to be at spillway invert elevation 916.0. The main flood event was routed through the project for each condition and alternative examined. The pool would exceed the top of the existing dam for duration of approximately 15 hours. The routing results are summarized in Table 2. As a result of this analysis, modification of the project would be required to enable it to safely pass the PMF event in accordance with current hydrologic and hydraulic design criteria.

Similar routings were also performed for the existing top of dam, elevation 931.3, and for the maximum flood control pool, or spillway crest level, elevation 916.0, as shown in Table 2.

Table 2. Dover Dam Routings

Flood (% PMF)	Peak Inflow (cfs)	Peak Outflow (cfs)	Maximum Pool (feet)
36	75,000	42,000	916.00
73	191,000	125,000	931.30
100	290,000	207,000	937.39

3. IMMINENT FAILURE FLOOD CONDITIONS

The Imminent Failure Flood (IFF) of concrete gravity dams, such as Dover Dam, can occur at various combinations of pool and tailwater conditions. Structural and geotechnical analyses have been performed to determine factors of safety of 1.0, 1.1 and 1.2 for various pool and tailwater conditions that could conceivably occur with the operation of Dover Dam during an array of flood events. This analysis is described in Section 3.2 of TAB IV and is illustrated in Figure IV-I.

District structural and geotechnical personnel have serious concerns that factors of safety will be compromised and a dam failure could occur prior to the pool reaching the maximum flood control pool, or spillway crest elevation 916. Thus, the Threshold Flood as defined in ER 1110-2-1155(top of existing dam minus appropriate freeboard), which defines hydrologic deficiency, is of minimal relevance for Dover since a potential failure could occur well below the Threshold Flood level due to IFF conditions.

The District is evaluating the operation of Dover, wherein is possible, to minimize the potential for failure until construction of the DSA project is completed.

As the Base Safety Condition has been determined by the downstream hazard analysis to be the 100% PMF, and the hydrologic Threshold Flood is 64% of the PMF (assuming 3 feet of freeboard), it is obvious that a significant safety deficiency exists, especially when compared to flood levels below the spillway crest (36% of the PMF) that pose a threat of failure of the dam. Therefore, it is urgent that this Evaluation Report be approved and the design and construction be implemented as soon as possible in order to remove the threat of dam failure and the potential for loss of life.

4. HAZARD ASSESSMENT

4.1 General. Hazard assessment for this study involves detailed evaluations downstream of the project to determine the potential for loss of life and economic damages associated with dam failure. The hazard assessments will define the relationship between flood inundation and adverse impacts (loss of life and economic damages) under the “with” and “without” dam failure conditions for various flood events. This relationship provides sufficient information to determine the flood that identifies the base safety standard.

The computer program Hydrologic Engineering Center River Analysis System (HEC-RAS) Hydrologic Engineering Center, Davis, California, provides state-of-the-art analysis of unsteady flow conditions, which occurs during a dam break, and it was used in this study as a technique for making estimates of the consequences of dam failures. This technique involves the determination of the flood plain that would be inundated downstream from Dover Dam without dam failure and the additional area that would be inundated by the flood wave with dam failure. The model also provides travel times, velocities, and flood elevations for determining the impacts of the flood wave on the downstream communities. For this study, the Dover Dam outflow hydrographs for each flood event were routed downstream along the Tuscarawas River to its confluence with the Muskingum River at Coshocton, then farther downstream to the confluence with the Ohio River at Marietta. Thus, over 150 miles of streams are modeled in this study to determine the behavior and characteristics of the flood wave as it progresses downstream from the dam. A total of 41 miles of Tuscarawas River, 125 miles of the Muskingum River are modeled as positive wave reaches. An additional 54 miles of the Little Tuscarawas River up to Piedmont, 9 miles of Little Tuscarawas River up to Tappan Dam, and 3 miles of the Walhonding River are modeled to account for negative wave affects and backwater flooding.

In accounting for the population that will be affected by flows from Dover Dam, the modeled area was divided into five reaches based upon travel times and flooding conditions. Reach 1 extends along the entire length of the Tuscarawas River from Dover Dam to New Philadelphia. Due to the proximity of this reach to Dover Dam, it would experience the largest incremental inundation depth between "with" and "without" dam failure conditions and the fastest increase in water depth. Reach 2 extends along the Tuscarawas River from New Philadelphia to the confluence of the Muskingum River. Reach 3 are backwater or negative wave areas that covers Stillwater Creek and Little Stillwater creek, tributaries of the Tuscarawas River. Reach 4 is a positive wave reach and extends along the Muskingum River from the confluence of the Tuscarawas River and Walhonding River to the confluence of the Muskingum River with the Ohio River. Reach 5 is a backwater or negative wave area that covers the city of Coshocton on the upper Muskingum River, Licking River, and Wills Creek.

The inundation maps will be provided during the Detailed Design Report phase. Flood profiles are provided in ANNEX C-1-1 showing the peak elevations, the initial conditions, non-damaging flow elevations and stream bed elevations for the study reaches. The hazardous assessment and results are presented in Appendix I.

5. HEC-RAS Unsteady Dam Break Model

5.1 General. The HEC-RAS computer model is considered to provide state-of-the-art analysis for unsteady flow conditions. The behavior of a large flood event through a system of streams and rivers is unsteady in nature. HEC-RAS simulates one-dimensional unsteady flow through a full network of open channels. The HEC-RAS computer model provides a state-of-the-art technique for determining a variety of characteristics of a flood wave, most notably flood wave travel times, velocities and flood wave depths that occur "with" and "without" dam failure. Therefore, the HEC-RAS computer program is the key to modeling the flood wave as it travels through the streams and rivers below Dover Dam. These characteristics of the flood wave as it is propagated through the downstream communities are calculated for the hazard assessment portion of this study.

The Reservoir Simulation (ResSim), Hydrologic Engineering Center, Davis, California, was employed to determine basinwide regulated outflow hydrographs at the projects and tributary inflow hydrographs for the HEC-RAS model. ResSim uses inflow and incidental hydrographs from HEC-HMS with project operation and downstream control point criteria to generate the resulting modified hydrographs. ResSim provided the proper hydrologic conditions and timing for full gate flow at the spillway invert. This was coupled with HEC-RAS input parameters to define the formation of the breach section during dam failure. Review of the existing conditions at Dover Dam by District Geotechnical and Hydraulic Engineers resulted in the selection of breach parameters as described in section 5.4. These breach parameters are comparable to the parameters used in Dam Safety Assurance Studies for other District projects with similar concrete gravity structures.

The HEC-RAS computer program requires specified boundary conditions at the beginning of each reach. Flow hydrographs for the upstream ends of the Little Tuscarawas River, Will Creek, and the Walhonding River were derived from the analysis of the design storm described. Lateral tributary inflow hydrographs and uniform lateral inflow hydrographs have also been used to account for incidental flows that will occur during the events considered in the study.

At Dover Dam, the boundary is defined by the inflow hydrograph at the dam. For the "without" dam failure conditions, these inflow hydrographs were directly input from HEC-HMS. From this point, HEC-RAS is used to compute the breach hydrograph for the “with” dam failure conditions.

A boundary condition is also required at the downstream end of the model. This study utilizes a table of elevations versus discharges. These elevations were obtained from a rating curve that was developed by U.S. Geological Survey.

Cross section geometry and Manning's "n" values were transferred to the HEC-RAS model from an existing Dam break model. Historical hydrographs from the January 2005 actual event was used to validate of the HEC-RAS model. Records from a storm event that occurred in 2005 were selected. The discharge hydrographs at various locations along Tuscarawas River and the Muskingum River that were calculated by the HEC-RAS model compare favorably to the historical hydrographs that were recorded during each of these flow events. Because the HEC-RAS computations approximately reproduce both the stages and the timing of the selected flood events, the model is considered to be suitable for use in determining the effects of the events that are presented in this study.

The initial flow conditions in the HEC-RAS model were selected to simulate the conditions that are likely to prevail prior to the beginning of spillway flow. Topographic features of the study area were derived from USGS 30-meter grid. This feature required special attention in the development of the HEC-RAS model. Cross sections were edited by hand and engineering judgment was utilized for on some of the mapping information.

5.2 Travel Time of Flood Wave Travel time for each cross section was developed. The travel time represents the difference between the time of the dam failure at the site of the dam and the time of maximum water surface elevation at the cross sections. In Tables 3 and 4 travel times are shown for the Tuscarawas and Muskingum River during the proposed raised dam with failure. Tables 3 and 4 are representative of both the existing conditions and the proposed raised dam condition because there is only one foot of difference between the two pool elevations. A more detailed analysis will be preformed during the detailed design phase.

Table 3
Travel Times for Raised Dam
With Failure on the Tuscarawas River

Tuscarawas River			
River Sta	Q Total (cfs)	W.S. Elev (ft)	Travel Time Hrs.
64.00	Dover Dam		
62.47	591437	923.74	0.0
62.34	566305	920.09	0.0
62.06	572422	920.91	0.0
61.78	567926	919.8	0.1
61.51	563377	918.63	0.1
61.23	560094	917.52	0.2
60.95	557464	916.35	0.2
60.68	555018	915.21	0.3
60.4	553073	914.1	0.3
60.12	551264	912.95	0.4
59.85	549586	911.82	0.4
59.57	548041	910.71	0.5
59.3	546845	909.57	0.5
59.02	545720	908.45	0.6
58.74	544463	907.29	0.6
58.47	543284	906.14	0.7
58.2	542349	904.98	0.8
57.93	541266	903.8	0.8
57.66	540034	902.59	0.9
57.39	538638	901.36	0.9
57.12	536893	900.12	1.0
56.85	534743	898.86	1.0
56.61	532301	897.74	1.1
56.37	528778	896.54	1.1
56.14	523533	895.16	1.2
55.9	515389	893.5	1.2
55.63	515650	892.03	1.3
55.36	510109	890.9	1.4
55.08	506185	890.03	1.4
54.81	503204.0	889.35	1.5
54.54	501651.5	888.84	1.6

Table 3(Con't)
Travel Times for Raised Dam
With Failure on the Tuscarawas River

Tuscarawas River			
River Sta	Q Total (cfs)	W.S. Elev (ft)	Travel Time Hrs.
54.51	501504	888.82	1.6
54.47	500917	888.75	1.7
54.2	499644	888.29	1.8
53.93	498582	887.83	1.9
53.67	497454	887.35	2.0
53.4	496385	886.86	2.1
53.13	495376	886.34	2.2
52.87	494415	885.79	2.2
52.6	493604	885.21	2.3
52.33	492532	884.56	2.4
52.06	491407	883.85	2.5
51.80	490404	883.03	2.6
51.52	489230	882.17	2.7
51.24	487980	881.36	2.8
50.96	487006	880.60	2.9
50.68	486046	879.90	2.9
50.40	496495	879.18	3.0
50.13	495602	878.55	3.1
49.85	494717	877.97	3.2
49.57	493843	877.44	3.3
48.98	490791	875.60	3.6
48.78	489377	874.88	3.6
48.58	487851	874.09	3.7
48.39	485729	873.22	3.8
48.19	483234	872.24	3.9
48.00	479724	871.13	3.9
47.89	451069	871.13	4.5
47.67	450633	870.58	4.6
47.41	449928	869.91	4.6
47.15	449157	869.11	4.7
46.89	447962	868.09	4.7
47.67	450633	870.58	4.6

Table 3 (Con't)
Travel Times for Raised Dam
With Failure on the Tuscarawas River

Tuscarawas River			
River Sta	Q Total (cfs)	W.S. Elev (ft)	Travel Time Hrs.
47.41	449928	869.91	4.6
47.15	449157	869.11	4.7
46.89	447962	868.09	4.7
46.62	447198	867.53	4.7
46.35	446786	867.12	4.8
46.08	446383	866.82	4.9
45.81	446154	866.59	4.9
45.57	445828	866.26	5.0
45.32	445347	865.81	5.1
45.08	444650	865.12	5.1
44.84	443140	863.85	5.1
44.60	442196	863.10	5.2
44.37	441230	862.45	5.2
44.14	440440	861.88	5.2
43.90	439649	861.36	5.3
43.65	439168	860.98	5.3
43.40	438875	860.70	5.4
43.15	438535	860.50	5.5
42.90	438528	860.35	5.5
42.61	438281	860.13	5.6
42.33	438002	859.79	5.7
42.05	437650	859.27	5.8
41.77	436912	858.31	5.8
41.54	436374	857.65	5.8
41.31	454299	856.95	5.9
41.08	453749	856.35	5.9
40.85	453145	855.83	6.0
40.60	452587	855.31	6.0
40.35	452180	854.85	6.0
40.09	451730	854.44	6.1
39.84	451383	854.07	6.1
39.59	450995	853.73	6.2

Table 3 (Con't)
Travel Times for Raised Dam
With Failure on the Tuscarawas River

Tuscarawas River			
River Sta	Q Total (cfs)	W.S. Elev (ft)	Travel Time Hrs.
39.34	450800	853.41	6.3
39.08	450524	853.12	6.3
38.83	450259	852.86	6.4
38.56	450004	852.49	6.5
38.29	449603	852.02	6.5
38.02	449131	851.37	6.6
37.75	448542	850.46	6.6
37.51	447979	849.66	6.6
37.28	447278	848.87	6.7
37.04	446722	848.10	6.7
36.81	445982	847.32	6.7
36.53	445261	846.72	6.8
36.26	445035	846.34	6.9
35.98	444771	846.09	6.9
35.70	444682	845.92	7.0
35.47	444407	845.67	7.1
35.23	444178	845.26	7.1
35.00	443652	844.56	7.2
34.76	442374	843.17	7.2
34.54	441414	842.26	7.2
34.31	440590	841.56	7.3
34.08	439934	841.05	7.3
33.86	439552	840.68	7.3
33.58	438948	840.19	7.4
33.31	438435	839.72	7.5
33.03	437837	839.27	7.5
32.75	437334	838.83	7.6
32.47	436927	838.41	7.6
32.20	436395	838.01	7.7
31.92	436040	837.63	7.8
31.64	435612	837.26	7.8
31.37	435188	836.91	7.9

Table 3 (Con't)
Travel Times for Raised Dam
With Failure on the Tuscarawas River

Tuscarawas River			
River Sta	Q Total (cfs)	W.S. Elev (ft)	Travel Time Hrs.
31.11	435020	836.60	8.0
30.86	434614	836.29	8.0
30.60	434306	835.96	8.1
30.35	434073	835.55	8.1
30.10	433657	835.06	8.2
29.85	433163	834.49	8.2
29.58	432709	833.92	8.3
29.31	432249	833.37	8.3
29.04	431675	832.85	8.4
28.78	431255	832.35	8.4
28.51	430912	831.87	8.5
28.24	430492	831.42	8.5
27.99	448097	830.98	8.6
27.75	447657	830.58	8.6
27.50	447497	830.21	8.7
27.25	447140	829.85	8.7
27.01	446712	829.52	8.8
26.76	446555	829.20	8.8
26.52	446184	828.87	8.9
26.27	445926	828.54	8.9
26.02	445710	828.21	9.0
25.78	445497	827.88	9.0
25.53	445224	827.55	9.1
25.28	444990	827.22	9.1
25.01	444635	826.84	9.2
24.74	444507	826.44	9.3
24.47	444135	826.01	9.3
24.19	443986	825.55	9.4
23.92	443626	825.05	9.4
23.65	443335	824.52	9.5
23.38	442954	823.93	9.5
23.18	442808	823.56	9.5

Table 3 (Con't)
Travel Times for Raised Dam
With Failure on the Tuscarawas River

Tuscarawas River			
River Sta	Q Total (cfs)	W.S. Elev (ft)	Travel Time Hrs.
22.99	442605	823.23	9.6
22.79	442519	822.92	9.6
22.52	442234	822.47	9.7
22.25	441986	821.99	9.7
21.98	441761	821.50	9.8
21.71	441512	820.98	9.8
21.44	458466	820.36	9.9
21.17	458094	819.71	9.9
20.90	457802	819.02	10.0
20.63	457273	818.27	10.0
20.36	456912	817.55	10.0
20.10	456479	816.86	10.1
19.83	456005	816.18	10.1
19.56	455496	815.53	10.2
19.29	455044	814.91	10.2
19.02	454620	814.33	10.3
18.76	454228	813.77	10.3
18.49	453739	813.25	10.4
18.20	453351	812.70	10.4
17.92	453024	812.15	10.5
17.65	452637	811.60	10.5
17.35	452160	811.06	10.6
17.07	451811	810.51	10.6
16.78	451468	809.97	10.7
16.50	451124	809.43	10.7
16.22	450813	808.93	10.8
15.94	450385	808.43	10.8
15.66	450170	807.95	10.9
15.38	449908	807.48	10.9
15.10	449614	807.03	11.0
14.82	449363	806.58	11.0
14.55	449115	806.15	11.1

Table 3 (Con't)
Travel Times for Raised Dam
With Failure on the Tuscarawas River

Tuscarawas River			
River Sta	Q Total (cfs)	W.S. Elev (ft)	Travel Time Hrs.
14.29	464399	805.71	11.1
14.04	464296	805.29	11.2
13.79	464064	804.85	11.2
13.53	463879	804.39	11.3
13.28	463747	803.89	11.3
13.03	463547	803.35	11.4
12.78	463393	802.72	11.4
12.52	463029	801.97	11.5
12.24	462840	801.26	11.5
11.96	462522	800.58	11.5
11.69	462221	799.92	11.6
11.41	461840	799.28	11.6
11.13	461552	798.66	11.7
10.85	461237	798.04	11.7
10.58	460944	797.44	11.8
10.29	460600	796.86	11.8
10.02	460309	796.29	11.9
9.74	460069	795.73	11.9
9.47	459749	795.19	12.0
9.19	459514	794.65	12.0

Table 3 (Con't)
Travel Times for Raised Dam
With Failure on the Tuscarawas River

Tuscarawas River			
River Sta	Q Total (cfs)	W.S. Elev (ft)	Travel Time Hrs.
8.92	459175	794.13	12.1
8.65	458941	793.61	12.1
8.31	458635	793.11	12.2
8.10	458385	792.61	12.2
7.83	458139	792.11	12.3
7.57	457890	791.59	12.3
7.31	457646	791.02	12.3
7.04	457352	790.42	12.4
6.78	457001	789.77	12.4
6.52	456642	789.05	12.5
6.26	456192	788.25	12.5
5.99	455624	787.45	12.5
5.72	455019	786.66	12.6
5.45	454355	785.89	12.6
5.18	453695	785.14	12.6
4.91	452975	784.41	12.7
4.65	452165	783.70	12.7
4.38	451506	783.02	12.8
4.11	450800	782.35	12.8
3.84	449882	781.72	12.8

Table 4
Travel Times for Raised Dam
With Failure on the Muskingum River

Table 4
Travel Times for Raised Dam
With Failure on the Muskingum River

Muskingum River			
River Sta	Q Total (cfs)	W.S. Elev (ft)	Travel Time Hrs.
103.00	458646	781.72	13.0
102.79	458432	780.63	13.0
102.57	458197	779.89	13.0
102.36	458085	779.30	13.1
102.08	473636	778.43	13.1
101.81	473479	777.79	13.1
101.54	473410	777.31	13.2
101.26	473377	776.95	13.2
100.99	473309	776.67	13.3
100.73	473220	776.32	13.3
100.47	473208	775.89	13.4
100.21	473123	775.33	13.4
99.94	472994	774.62	13.5
99.68	472881	773.66	13.5
99.42	472597	772.33	13.5
99.16	471541	770.25	13.6
98.90	469921	768.87	13.6
98.64	466822	767.57	13.6
98.38	462494	766.41	13.6
98.12	456994	765.40	13.7
97.86	450947	764.55	13.7
97.61	445717	763.88	13.7
97.34	441248	763.34	13.8
97.09	438020	762.93	13.8
96.82	434771	762.49	13.9
96.56	431478	762.05	13.9
96.31	428588	761.61	14.0
96.04	425364	761.17	14.0
95.78	422442	760.71	14.1
95.52	419179	760.25	14.1
95.26	416392	759.77	14.1
95.00	413465	759.27	14.2

Table 4 (Con't)
Travel Times for Raised Dam
With Failure on the Muskingum River

Muskingum River			
River Sta	Q Total (cfs)	W.S. Elev (ft)	Travel Time Hrs.
94.89	410701	758.85	14.2
94.79	408671	758.49	14.3
94.69	406328	758.19	14.3
94.58	404935	757.93	14.4
94.48	404903	757.93	14.5
94.38	403882	757.74	14.6
94.28	403271	757.57	14.6
94.22	402711	757.41	14.7
94.17	401787	757.26	14.8
94.12	401517	757.13	14.9
94.07	400992	757.00	15.0
94.03	400686	456.91	15.1
94.01	400528	756.89	15.1
93.96	400269	756.78	15.2
93.91	399869	756.68	15.3
93.86	399629	756.59	15.4
93.81	399342	756.50	15.5
93.54	398882	756.42	15.6
93.28	398925	756.35	15.7
93.01	398665	756.28	15.8
92.75	398583	756.21	15.9
92.48	398292	756.15	16.1
92.22	398333	756.09	16.2
91.95	398072	756.03	16.3
91.69	398031	755.98	16.4
91.43	397892	755.93	16.5
91.16	397954	755.88	16.7
90.89	397799	755.83	16.8
90.63	397787	755.79	16.9
90.37	397734	755.75	17.1
90.12	397703	755.69	17.2
89.88	397651	755.62	17.3

Table 4 (Con't)
Travel Times for Raised Dam
With Failure on the Muskingum River

Muskingum River			
River Sta	Q Total (cfs)	W.S. Elev (ft)	Travel Time Hrs.
89.63	397484	755.52	17.4
89.39	397411	755.35	17.5
89.14	397253	755.06	17.5
88.90	396802	754.42	17.6
88.64	396412	754.00	17.6
88.39	396133	753.58	17.6
88.14	395805	753.15	17.7
87.89	395451	752.72	17.7
87.64	395094	752.29	17.8
87.37	394761	751.92	17.8
87.10	394450	751.57	17.8
86.83	394258	751.25	17.9
86.56	394019	750.95	17.9
86.29	393831	750.68	18.0
86.05	393504	750.44	18.1
85.75	393458	750.21	18.1
85.48	393298	750.01	18.2
85.21	393119	749.82	18.2
84.94	393007	749.65	18.3
84.68	392897	749.44	18.4
84.41	392686	749.21	18.4
84.15	392537	748.96	18.5
83.89	392332	748.68	18.5
83.62	392209	748.38	18.6
83.37	391986	748.04	18.6
83.10	391744	747.67	18.7
82.84	391522	747.26	18.7
82.58	391201	746.80	18.8
82.32	390895	746.29	18.8
82.05	390483	745.70	18.9
81.79	390043	745.02	18.9
81.52	389551	744.42	18.9

Table 4 (Con't)
Travel Times for Raised Dam
With Failure on the Muskingum River

Muskingum River			
River Sta	Q Total (cfs)	W.S. Elev (ft)	Travel Time Hrs.
81.25	389136	743.82	19.0
82.58	391201	746.80	18.8
82.32	390895	746.29	18.8
82.05	390483	745.70	18.9
81.79	390043	745.02	18.9
81.52	389551	744.42	18.9
81.25	389136	743.82	19.0
82.58	391201	746.80	18.8
82.32	390895	746.29	18.8
82.05	390483	745.70	18.9
81.79	390043	745.02	18.9
81.52	389551	744.42	18.9
81.25	389136	743.82	19.0
82.58	391201	746.80	18.8
82.32	390895	746.29	18.8
82.05	390483	745.70	18.9
81.79	390043	745.02	18.9
81.52	389551	744.42	18.9
81.25	389136	743.82	19.0
82.58	391201	746.80	18.8
75.95	380045	734.52	19.8
75.89	379803	734.21	19.9
75.84	379480	733.88	19.9
75.78	379079	733.55	20.0
75.73	378731	733.20	20.1
75.67	378354	732.83	20.1
75.62	377977	732.45	20.2
75.56	377548	732.05	20.2
75.51	378260	732.05	21.8
75.45	378018	731.61	21.9
75.20	377867	731.23	21.9
74.94	377681	730.85	22.0

Table 4 (Con't)
Travel Times for Raised Dam
With Failure on the Muskingum River

Muskingum River			
River Sta	Q Total (cfs)	W.S. Elev (ft)	Travel Time Hrs.
74.69	377476	730.45	22.1
74.44	377232	730.04	22.1
74.19	377026	729.62	22.2
73.93	376874	729.18	22.2
73.68	376608	728.71	22.3
73.48	376416	728.37	22.3
73.27	376280	728.04	22.4
73.03	376124	727.71	22.4
72.78	375930	727.40	22.5
72.54	375735	727.10	22.5
72.29	375539	726.81	22.6
72.05	375479	726.55	22.7
71.80	375323	726.29	22.7
71.56	375206	726.05	22.8
71.29	375012	725.76	22.9
71.02	374820	725.48	22.9
70.76	374743	725.21	23.0
70.49	374609	724.94	23.1
70.22	374400	724.68	23.2
69.96	374363	724.42	23.3
69.69	374213	724.17	23.3
69.42	374085	723.93	23.4
69.15	373957	723.67	23.5
68.89	373901	723.42	23.6
68.62	373794	723.17	23.7
68.36	373668	722.91	23.7
68.09	373561	722.66	23.8
67.82	373453	722.39	23.9
67.56	373294	722.12	24.0
67.29	373135	721.84	24.0
67.02	373045	721.63	24.1
66.74	372992	721.42	24.2

Table 4 (Con't)
Travel Times for Raised Dam
With Failure on the Muskingum River

Muskingum River			
River Sta	Q Total (cfs)	W.S. Elev (ft)	Travel Time Hrs.
66.47	372867	721.20	24.2
66.19	372797	720.98	24.3
65.92	372725	720.75	24.4
65.64	372571	720.50	24.5
65.37	372450	720.25	24.6
65.11	372364	720.00	24.6
64.85	372296	719.76	24.7
64.59	372179	719.51	24.8
64.33	372111	719.26	24.9
64.06	371965	719.01	25.0
63.80	371867	718.76	25.0
63.54	371740	718.50	25.1
63.28	371709	718.24	25.2
63.00	371631	717.99	25.3
62.71	371540	717.76	25.4
62.43	371524	717.54	25.5
62.15	371434	717.33	25.6
61.86	371377	717.13	25.7
61.58	371318	716.93	25.8
61.29	371234	716.74	25.9
61.01	371261	716.55	26.0
60.75	371181	716.34	26.1
60.50	371100	716.09	26.1
60.24	371046	715.81	26.2
59.99	370929	715.49	26.3
59.73	370901	715.12	26.4
59.48	370744	714.68	26.4
59.22	370641	714.16	26.5
58.96	370495	713.75	26.5
58.71	370402	713.34	26.6
58.45	370336	712.94	26.7
58.20	370243	712.56	26.7

Table 4 (Con't)
Travel Times for Raised Dam
With Failure on the Muskingum River

Muskingum River			
River Sta	Q Total (cfs)	W.S. Elev (ft)	Travel Time Hrs.
57.94	370111	712.18	26.8
57.68	370058	711.80	26.8
57.43	369951	711.44	26.9
57.17	369846	711.08	27.0
56.89	369793	710.73	27.0
56.60	369661	710.39	27.1
56.32	369596	710.07	27.2
56.04	369557	709.75	27.2
55.76	369490	709.45	27.3
55.47	369399	709.16	27.4
55.19	369322	708.87	27.4
54.93	369257	708.59	27.5
54.67	369193	708.31	27.6
54.41	369128	708.02	27.6
54.15	369052	707.73	27.7
53.89	368963	707.45	27.8
53.63	368938	707.16	27.8
53.37	368813	706.87	27.9
53.11	368788	706.58	28.0
52.83	368699	706.25	28.0
52.56	368601	705.89	28.1
52.29	368515	705.52	28.2
52.01	368440	705.11	28.2
51.73	368304	704.68	28.3
51.46	368204	704.22	28.3
51.18	368054	703.71	28.4
50.91	367953	703.16	28.5
50.64	367877	702.75	28.5
50.37	367737	702.38	28.6
50.10	367649	702.03	28.6
49.83	367610	701.70	28.7
49.50	367509	701.40	28.8

Table 4 (Con't)
Travel Times for Raised Dam
With Failure on the Muskingum River

Muskingum River			
River Sta	Q Total (cfs)	W.S. Elev (ft)	Travel Time Hrs.
49.29	367458	701.12	28.8
49.01	367396	700.79	28.9
48.73	367284	700.47	29.0
48.46	367185	700.15	29.1
48.20	367148	699.85	29.1
47.96	367049	699.56	29.2
47.71	366954	699.26	29.2
47.46	366941	698.97	29.3
47.21	366867	698.67	29.4
46.96	366808	698.38	29.4
46.72	366711	698.08	29.5
46.43	366651	697.72	29.6
46.15	366555	697.35	29.6
45.87	366459	696.97	29.7
45.59	366340	696.58	29.8
45.31	366256	696.18	29.8
45.03	366160	695.76	29.9
44.75	366039	695.33	30.0
44.47	365967	694.89	30.0
44.19	365869	694.43	30.1
43.91	365710	693.96	30.2
43.63	365586	693.47	30.2
43.4	365448	692.96	30.3
43.1	365283	692.43	30.3
42.8	365166	691.88	30.4
42.5	364983	691.30	30.4
42.2	364728	690.70	30.5
42.0	364536	690.07	30.5
41.7	364325	689.54	30.6
41.4	364153	689.01	30.6
41.1	363950	688.51	30.7
40.8	363759	688.01	30.8

Table 5 (Con't)
Travel Times for Raised Dam
With Failure on the Muskingum River

Muskingum River			
River Sta	Q Total (cfs)	W.S. Elev (ft)	Travel Time Hrs.
103.00	458646	781.72	13.0
102.79	458432	780.63	13.0
102.57	458197	779.89	13.0
102.36	458085	779.30	13.1
102.08	473636	778.43	13.1
101.81	473479	777.79	13.1
101.54	473410	777.31	13.2
101.26	473377	776.95	13.2
100.99	473309	776.67	13.3
100.73	473220	776.32	13.3
100.47	473208	775.89	13.4
100.21	473123	775.33	13.4
99.94	472994	774.62	13.5
99.68	472881	773.66	13.5
99.42	472597	772.33	13.5
99.16	471541	770.25	13.6
98.90	469921	768.87	13.6
98.64	466822	767.57	13.6
98.38	462494	766.41	13.6
98.12	456994	765.40	13.7
97.86	450947	764.55	13.7
97.61	445717	763.88	13.7
97.34	441248	763.34	13.8
97.09	438020	762.93	13.8
96.82	434771	762.49	13.9
96.56	431478	762.05	13.9
96.31	428588	761.61	14.0
96.04	425364	761.17	14.0
95.78	422442	760.71	14.1
95.52	419179	760.25	14.1
95.26	416392	759.77	14.1
95.00	413465	759.27	14.2

Table 4 (Con't)
Travel Times for Raised Dam
With Failure on the Muskingum River

Muskingum River			
River Sta	Q Total (cfs)	W.S. Elev (ft)	Travel Time Hrs.
94.89	410701	758.85	14.2
94.79	408671	758.49	14.3
94.69	406328	758.19	14.3
94.58	404935	757.93	14.4
94.48	404903	757.93	14.5
94.38	403882	757.74	14.6
94.28	403271	757.57	14.6
94.22	402711	757.41	14.7
94.17	401787	757.26	14.8
94.12	401517	757.13	14.9
94.07	400992	757.00	15.0
94.03	400686	456.91	15.1
94.01	400528	756.89	15.1
93.96	400269	756.78	15.2
93.91	399869	756.68	15.3
93.86	399629	756.59	15.4
93.81	399342	756.50	15.5
93.54	398882	756.42	15.6
93.28	398925	756.35	15.7
93.01	398665	756.28	15.8
92.75	398583	756.21	15.9
92.48	398292	756.15	16.1
92.22	398333	756.09	16.2
91.95	398072	756.03	16.3
91.69	398031	755.98	16.4
91.43	397892	755.93	16.5
91.16	397954	755.88	16.7
90.89	397799	755.83	16.8
90.63	397787	755.79	16.9
90.37	397734	755.75	17.1
90.12	397703	755.69	17.2
89.88	397651	755.62	17.3

Table 4 (Con't)
Travel Times for Raised Dam
With Failure on the Muskingum River

Muskingum River			
River Sta	Q Total (cfs)	W.S. Elev (ft)	Travel Time Hrs.
89.63	397484	755.52	17.4
89.39	397411	755.35	17.5
89.14	397253	755.06	17.5
88.90	396802	754.42	17.6
88.64	396412	754.00	17.6
88.39	396133	753.58	17.6
88.14	395805	753.15	17.7
87.89	395451	752.72	17.7
87.64	395094	752.29	17.8
87.37	394761	751.92	17.8
87.10	394450	751.57	17.8
86.83	394258	751.25	17.9
86.56	394019	750.95	17.9
86.29	393831	750.68	18.0
86.05	393504	750.44	18.1
85.75	393458	750.21	18.1
85.48	393298	750.01	18.2
85.21	393119	749.82	18.2
84.94	393007	749.65	18.3
84.68	392897	749.44	18.4
84.41	392686	749.21	18.4
84.15	392537	748.96	18.5
83.89	392332	748.68	18.5
83.62	392209	748.38	18.6
83.37	391986	748.04	18.6
83.10	391744	747.67	18.7
82.84	391522	747.26	18.7
82.58	391201	746.80	18.8
82.32	390895	746.29	18.8
82.05	390483	745.70	18.9
81.79	390043	745.02	18.9
81.52	389551	744.42	18.9

Table 4 (Con't)
Travel Times for Raised Dam
With Failure on the Muskingum River

Muskingum River			
River Sta	Q Total (cfs)	W.S. Elev (ft)	Travel Time Hrs.
81.25	389136	743.82	19.0
82.58	391201	746.80	18.8
82.32	390895	746.29	18.8
82.05	390483	745.70	18.9
81.79	390043	745.02	18.9
81.52	389551	744.42	18.9
81.25	389136	743.82	19.0
82.58	391201	746.80	18.8
82.32	390895	746.29	18.8
82.05	390483	745.70	18.9
81.79	390043	745.02	18.9
81.52	389551	744.42	18.9
81.25	389136	743.82	19.0
82.58	391201	746.80	18.8
82.32	390895	746.29	18.8
82.05	390483	745.70	18.9
81.79	390043	745.02	18.9
81.52	389551	744.42	18.9
81.25	389136	743.82	19.0
82.58	391201	746.80	18.8
75.95	380045	734.52	19.8
75.89	379803	734.21	19.9
75.84	379480	733.88	19.9
75.78	379079	733.55	20.0
75.73	378731	733.20	20.1
75.67	378354	732.83	20.1
75.62	377977	732.45	20.2
75.56	377548	732.05	20.2
75.51	378260	732.05	21.8
75.45	378018	731.61	21.9
75.20	377867	731.23	21.9
74.94	377681	730.85	22.0

Table 4 (Con't)
Travel Times for Raised Dam
With Failure on the Muskingum River

Muskingum River			
River Sta	Q Total (cfs)	W.S. Elev (ft)	Travel Time Hrs.
74.69	377476	730.45	22.1
74.44	377232	730.04	22.1
74.19	377026	729.62	22.2
73.93	376874	729.18	22.2
73.68	376608	728.71	22.3
73.48	376416	728.37	22.3
73.27	376280	728.04	22.4
73.03	376124	727.71	22.4
72.78	375930	727.40	22.5
72.54	375735	727.10	22.5
72.29	375539	726.81	22.6
72.05	375479	726.55	22.7
71.80	375323	726.29	22.7
71.56	375206	726.05	22.8
71.29	375012	725.76	22.9
71.02	374820	725.48	22.9
70.76	374743	725.21	23.0
70.49	374609	724.94	23.1
70.22	374400	724.68	23.2
69.96	374363	724.42	23.3
69.69	374213	724.17	23.3
69.42	374085	723.93	23.4
69.15	373957	723.67	23.5
68.89	373901	723.42	23.6
68.62	373794	723.17	23.7
68.36	373668	722.91	23.7
68.09	373561	722.66	23.8
67.82	373453	722.39	23.9
67.56	373294	722.12	24.0
67.29	373135	721.84	24.0
67.02	373045	721.63	24.1
66.74	372992	721.42	24.2

Table 4 (Con't)
Travel Times for Raised Dam
With Failure on the Muskingum River

Muskingum River			
River Sta	Q Total (cfs)	W.S. Elev (ft)	Travel Time Hrs.
66.47	372867	721.20	24.2
66.19	372797	720.98	24.3
65.92	372725	720.75	24.4
65.64	372571	720.50	24.5
65.37	372450	720.25	24.6
65.11	372364	720.00	24.6
64.85	372296	719.76	24.7
64.59	372179	719.51	24.8
64.33	372111	719.26	24.9
64.06	371965	719.01	25.0
63.80	371867	718.76	25.0
63.54	371740	718.50	25.1
63.28	371709	718.24	25.2
63.00	371631	717.99	25.3
62.71	371540	717.76	25.4
62.43	371524	717.54	25.5
62.15	371434	717.33	25.6
61.86	371377	717.13	25.7
61.58	371318	716.93	25.8
61.29	371234	716.74	25.9
61.01	371261	716.55	26.0
60.75	371181	716.34	26.1
60.50	371100	716.09	26.1
60.24	371046	715.81	26.2
59.99	370929	715.49	26.3
59.73	370901	715.12	26.4
59.48	370744	714.68	26.4
59.22	370641	714.16	26.5
58.96	370495	713.75	26.5
58.71	370402	713.34	26.6
58.45	370336	712.94	26.7
58.20	370243	712.56	26.7

Table 4 (Con't)
Travel Times for Raised Dam
With Failure on the Muskingum River

Muskingum River			
River Sta	Q Total (cfs)	W.S. Elev (ft)	Travel Time Hrs.
57.94	370111	712.18	26.8
57.68	370058	711.80	26.8
57.43	369951	711.44	26.9
57.17	369846	711.08	27.0
56.89	369793	710.73	27.0
56.60	369661	710.39	27.1
56.32	369596	710.07	27.2
56.04	369557	709.75	27.2
55.76	369490	709.45	27.3
55.47	369399	709.16	27.4
55.19	369322	708.87	27.4
54.93	369257	708.59	27.5
54.67	369193	708.31	27.6
54.41	369128	708.02	27.6
54.15	369052	707.73	27.7
53.89	368963	707.45	27.8
53.63	368938	707.16	27.8
53.37	368813	706.87	27.9
53.11	368788	706.58	28.0
52.83	368699	706.25	28.0
52.56	368601	705.89	28.1
52.29	368515	705.52	28.2
52.01	368440	705.11	28.2
51.73	368304	704.68	28.3
51.46	368204	704.22	28.3
51.18	368054	703.71	28.4
50.91	367953	703.16	28.5
50.64	367877	702.75	28.5
50.37	367737	702.38	28.6
50.10	367649	702.03	28.6
49.83	367610	701.70	28.7
49.50	367509	701.40	28.8

Table 4 (Con't)
Travel Times for Raised Dam
With Failure on the Muskingum River

Muskingum River			
River Sta	Q Total (cfs)	W.S. Elev (ft)	Travel Time Hrs.
49.29	367458	701.12	28.8
49.01	367396	700.79	28.9
48.73	367284	700.47	29.0
48.46	367185	700.15	29.1
48.20	367148	699.85	29.1
47.96	367049	699.56	29.2
47.71	366954	699.26	29.2
47.46	366941	698.97	29.3
47.21	366867	698.67	29.4
46.96	366808	698.38	29.4
46.72	366711	698.08	29.5
46.43	366651	697.72	29.6
46.15	366555	697.35	29.6
45.87	366459	696.97	29.7
45.59	366340	696.58	29.8
45.31	366256	696.18	29.8
45.03	366160	695.76	29.9
44.75	366039	695.33	30.0
44.47	365967	694.89	30.0
44.19	365869	694.43	30.1
43.91	365710	693.96	30.2
43.63	365586	693.47	30.2
43.4	365448	692.96	30.3
43.1	365283	692.43	30.3
42.8	365166	691.88	30.4
42.5	364983	691.30	30.4
42.2	364728	690.70	30.5
42.0	364536	690.07	30.5
41.7	364325	689.54	30.6
41.4	364153	689.01	30.6
41.1	363950	688.51	30.7
40.8	363759	688.01	30.8

Table 4 (Con't)
Travel Times for Raised Dam
With Failure on the Muskingum River

Muskingum River			
River Sta	Q Total	W.S. Elev	Travel Time
	(cfs)	(ft)	Hrs.
40.5	363550	687.53	30.8
40.3	363308	687.06	30.9
40.0	363170	686.60	30.9
39.7	362954	686.16	31.0
39.4	362751	685.73	31.1
39.1	362547	685.32	31.1
38.8	362388	684.92	31.2
38.55	362149	684.53	31.2
38.27	361971	684.15	31.3
37.99	361810	683.78	31.4
37.7	361631	683.43	31.5
37.42	361435	683.09	31.5
37.14	361321	682.76	31.6
36.86	361157	682.45	31.7
36.57	360929	682.12	31.8
36.29	360781	681.79	31.8
36.01	360633	681.47	31.9
35.73	360453	681.14	32
35.45	360256	680.81	32.1
35.17	360124	680.48	32.2
34.89	359893	680.16	32.2
34.61	359729	679.83	32.3
34.33	359548	679.51	32.4
34.05	359399	679.18	32.5
33.77	359200	678.85	32.6
33.49	359101	678.53	32.6
33.21	358819	678.21	32.7
32.93	358702	677.88	32.8
32.6	358436	677.56	32.9
32.37	358321	677.24	33
32.09	358169	676.92	33.1
31.81	358002	676.59	33.1

Table 4 (Con't)
Travel Times for Raised Dam
With Failure on the Muskingum River

Muskingum River			
River Sta	Q Total	W.S. Elev	Travel Time
	(cfs)	(ft)	Hrs.
31.54	357802	676.27	33.2
31.27	357617	675.95	33.3
31.00	357451	675.62	33.4
30.70	357199	675.29	33.5
30.46	357113	674.96	33.5
30.19	356897	674.62	33.6
29.92	356679	674.28	33.7
29.65	356512	673.94	33.8
29.37	356260	673.59	33.9
29.10	356160	673.24	33.9
28.83	355959	672.89	34.0
28.56	355726	672.53	34.1
28.29	355543	672.16	34.
28.02	355264	671.79	34.
28.02	355264	671.79	34
27.75	355148	671.42	34
27.48	354949	671.04	34
27.21	354784	670.66	34.
26.94	354556	670.28	34.5
26.66	354442	669.95	34.6
26.38	354281	669.63	34.7
26.10	354152	669.31	34.7
25.82	353945	668.99	34.8
25.54	353850	668.67	34.9
25.26	353676	668.34	35.0
24.98	353519	667.99	35.0
24.70	353284	667.63	35.1
24.42	353111	667.25	35.2
24.15	352937	666.82	35.2
23.89	352745	666.47	35.3
23.63	352649	666.11	35.4
23.38	352423	665.74	35.4

Table 4 (Con't)
Travel Times for Raised Dam
With Failure on the Muskingum River

Muskingum River			
River Sta	Q Total	W.S. Elev	Travel Time
	(cfs)	(ft)	Hrs.
23.12	352277	665.37	35.5
22.87	352065	665.00	35.5
22.61	351819	664.62	35.6
22.36	351687	664.24	35.7
22.08	351420	663.86	35.7
21.81	351237	663.49	35.8
21.54	351102	663.12	35.8
21.27	350883	662.76	35.9
20.99	350680	662.41	36.0
20.72	350493	662.06	36.0
20.45	350339	661.72	36.1
20.18	350153	661.40	36.2
19.91	350000	661.07	36.2
19.63	349811	660.76	36.3
19.36	349640	660.45	36.4
19.09	349486	660.15	36.4
18.82	349299	659.85	36.5
18.55	349162	659.57	36.6
18.27	349078	659.29	36.6
18.00	348908	659.01	36.7
17.73	348738	658.74	36.8
17.46	348637	658.48	36.8
17.19	348470	658.23	36.9
16.92	348402	657.98	37.0
16.65	348286	657.74	37.1
16.38	348170	657.50	37.1
16.11	348039	657.26	37.2
15.84	347958	657.03	37.3
15.57	347779	656.81	37.4

Table 4 (Con't)
Travel Times for Raised Dam
With Failure on the Muskingum River

Muskingum River			
River Sta	Q Total	W.S. Elev	Travel Time
	(cfs)	(ft)	Hrs.
15.30	347731	656.59	37.5
15.03	347620	656.37	37.5
14.76	347573	656.16	37.6
14.49	347470	655.95	37.7
14.22	347402	655.75	37.8
13.95	347324	655.55	37.9
13.68	347236	655.36	38.0
13.41	347191	655.17	38.1
13.14	347089	654.99	38.2
12.87	347032	654.82	38.3
12.60	346961	654.65	38.4
12.33	346974	654.49	38.5
12.06	346880	654.33	38.6
11.77	346788	654.15	38.7
11.49	346775	653.96	38.8
11.20	346737	653.77	38.9
10.92	346676	653.57	39.0
10.64	346604	653.38	39.1
10.30	346569	653.18	39.3
10.07	346500	652.98	39.4
9.78	346533	652.78	39.5
9.50	346468	652.58	39.6
9.22	346446	652.38	39.7
8.93	346384	652.17	39.8
8.65	346363	651.96	39.9
8.37	346335	651.76	40.0
8.08	346297	651.55	40.1
7.80	346287	651.34	40.2
7.51	346250	651.12	40.3

Table 4 (Con't)
Travel Times for Raised Dam
With Failure on the Muskingum River

Muskingum River			
River Sta	Q Total	W.S. Elev	Travel Time
	(cfs)	(ft)	Hrs.
7.23	346224	650.91	40.4
6.95	346207	650.70	40.5
6.66	346199	650.49	40.5
6.38	346174	650.27	40.6
6.10	346152	650.06	40.7
5.81	346137	649.86	40.8
5.50	346116	649.67	40.9
5.24	346095	649.48	41.0
4.96	346113	649.30	41.1
4.67	346084	649.12	41.2
4.39	346082	648.94	41.3
4.11	346087	648.77	41.4
3.82	346076	648.60	41.5
3.54	346049	648.43	41.6
3.20	346061	648.27	41.7
2.90	346064	648.11	41.8
2.69	346049	647.96	41.9
2.40	346051	647.81	42.0
2.12	346048	647.66	42.1
1.83	346052	647.52	42.2
1.55	346038	647.38	42.4
1.27	346045	647.24	42.5
1.02	346044	647.07	42.6
0.76	346042	646.89	42.7
0.51	346041	646.70	42.7
0.25	346041	646.50	42.8

5.3. Hypothetical Maximum Dam Failure and Downstream Inundation. The hypothetical maximum dam failure flows and downstream inundation are computed to define the maximum lateral boundaries for the collection of data on economic damages and loss of life. The maximum lateral extent and depth of flooding from dam failure are computed by assuming the dam crest is raised to prevent overtopping during the PMF event and assuming failure occurs at the peak pool elevation. All of the discharge from Dover Dam before dam failure is from the spillway and the outlet works. Since all lesser failure and non-failure floods inundate a subset of this area, the collection of data on damageable property and population at risk for the maximum limits provides sufficient information to determine the damages and population at risk for the lesser flood events. The hypothetical maximum flood limits were defined for this study by routing the PMF event "with" dam failure through the downstream valley using the HEC-RAS model. The failure parameters were determined based on past studies. The time required for failure to occur was 0.1 hours (6 minutes). The failure would be located at the spillway with a breach of 270 feet wide with a bottom elevation of 867.0. This breach condition was the same for each failure condition, as shown in Figure 5.

Table 5
Dover Dam Breach Parameters

Time to Completion of Breach	0.1 Hour (6 minutes)
Side Slopes of Breach	1.0 Vertical on 0.0 Horizontal
Bottom Width of Breach	270 Feet
Elevation of Bottom of Breach	867
Lake Level When Failure Begins100% PMF	937.3

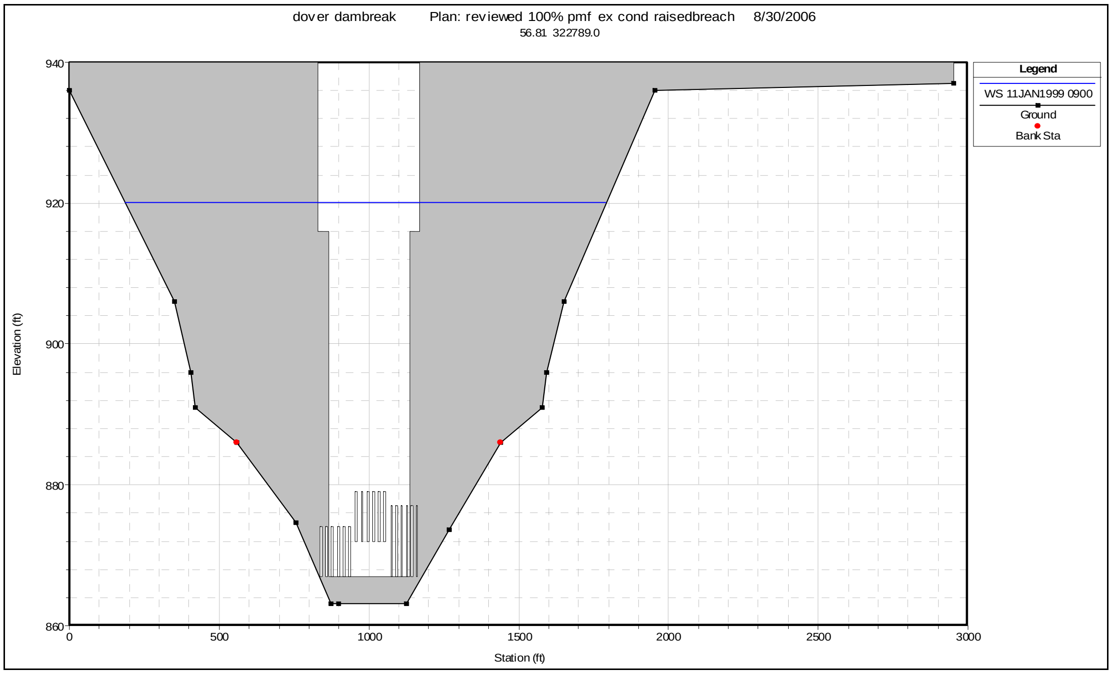

Figure 5 (Dam Break Cross Section)

5.4 Incremental Impacts of Dam Failure. A dam failure occurring at peak pool would cause significant incremental damage above that which would occur without dam failure. Refer to Appendix I, for detailed economic damages, population at risk and hazard assessment.

6. FREEBOARD

The freeboard required for Dover Dam was determined using ER 1110-8-2(FR), dated 1 March 1991, titled: Inflow Design Floods for Dams and Reservoirs. The results of the freeboard determination for Dover Dam were 2.5 feet. The ER 1110-8-2(FR) states “the minimum freeboard will be five feet for embankment dams and three feet for concrete dams or greater.” This Engineering Regulations was waived for previous Dam Safety Projects. However, the cost of 3.0 feet of freeboard for Dover dam was included in the cost estimate contingency. This issue will be examined in detail during the Detailed Design Report (DDR).

7. MODIFICATIONS FOR CORRECTION OF SPILLWAY DEFICIENCY

An array of alternatives was considered for correction of the spillway deficiency of Dover Dam. These alternatives are listed and discussed in Section 2.4.1 of the Main Report. The array was condensed by a screening process, as described in Section 2.4.2 of the Main Report. Then, a detailed analysis was performed for each of the remaining alternatives, including flood routings of the 100% PMF for both the “with” and “without” dam failure scenarios. Selection of the Recommended Plan, as described in Section 5 of the Main Report, indicates that the “Raise Dam” with anchoring plan provided the most reliable satisfaction of project objectives minimizes cost and has the least adverse environmental impacts.

8. THREATENED POPULATION

8.1 General. Since the potential for loss of life from dam failure is the primary motivation for considering investments in dam safety improvements, the purpose of this section is to assess the potential for a significant number of people to actually be threatened by the flood waters resulting from failure of the Dover Dam. A probabilistic risk assessment to determine an expected number of lives lost was made for this study. However, the probabilistic method that was suggested is less than ideal for large dam failure events such as the PMF. Thus, threatened population is defined as those people likely to be exposed to flood waters assuming that warnings have been issued in a manner that would be expected under current conditions. The discussion of threatened population in this report is primarily oriented to Reach 1 where the arrival of hazardous flows may occur too rapidly for effective notification and evacuation of the entire population affected by floodwaters.

The incremental population impacted by dam failure above the without dam failure limits was discussed in previous sections. The emphasis in this section will be on the threatened population that would be affected by dam failure flows within two hours after the beginning of dam failure. It should be noted that this population is different from the incremental population impacted by dam failure above the without failure limits. Some of these people are below the peak flooding limits without dam failure. These people might normally have time to evacuate but become threatened by the rapid arrival of flood waters due to dam failure. Thus, two groups of people have been identified as those most likely to be threatened in the event of dam failure during a major flood event.

A warning and evacuation plan can significantly reduce the number of people threatened by the dam failure flood waters provided there is sufficient notification time to initiate warning and evacuation. However, the evaluation of the threatened population requires the consideration of many factors. The effectiveness of warning and evacuation is a major one of these factors, and is extremely difficult to evaluate. Before examining the population that would be threatened within the first two hours of dam failure, the threat to the incremental population between "with" and "without" dam failure will be discussed. Since this population is only affected by dam failure, it is most likely that they will not be prepared to evacuate. Even if they receive the warning, many of these people may not perceive it as serious, others may refuse to take action, and some may take wrong actions such as an evacuation route that is already flooded or an evacuation center that is in imminent danger. The decision and notice for these people to evacuate would be well into the flood event. As a result, most of the main evacuation routes may be inundated or congested with traffic. Bridges may be washed out and residents may be isolated. Also, the number of people at risk in this increment will most likely be larger than indicated since people evacuating from the lower flooding limits may move into this area. This would especially be true if the local officials have developed emergency shelters in this incremental area. It should be noted that in the study area, some of the pre-planned shelters are within the inundated area. Further discussion on flood impacted evacuation routes at the major communities will be presented later in this section. In addition, with a dam failure condition occurring well into the flood event, the probability is great that there will already be significant loss of communications due to the loss of utilities such as electricity and telephone service. Radio communications can be impacted since transmission capabilities may be reduced when using auxiliary power sources and some communities might still depend on telephone links in their radio system. With these factors in mind and considering that the arrival times of hazardous flows in this increment range from 5 hours before dam failure to 40 hours prior to failure in the Tuscarawas River area, a significant portion of these people will actually be threatened by flooding due to dam failure.

8.2 Calculation of Loss of Life. In addressing the threatened population for dam failure during major flood events equations from the U.S. Department of the Interior Bureau of Reclamation DSO-99-06 “A Procedure for Estimating Loss of Life Caused by Dam Failure” was used to develop Table 6. As noted in DSO-99-06 closing comments “High Severity flooding is <u>not</u> well represented in the data base” thus the equations, based on flood severity is not applicable for a concrete gravity dam failure by the 100 % PMF event. The calculations for the loss of life for flood severity equation are shown in Table 6. However, an additional equation was used which is based on warning time not flood severity. Recent events showed the U.S. Army Corps of Engineers monitors Dams very extensively during major flood events such as the January 2005 flood event, so issuing warnings for such a flood event would be a reasonable assumption. The equation used for loss of life calculation, with regard to warning time, is as followed:

$$\text{Deaths} = \frac{PAR}{((1 + 13.2277(PAR^{0.440})e^{[2.982(wt) - 3.790]}}$$

Where:

PAR = Population at Risk
wt = is the estimated warning time.

This equation was determined to be the best for the 100 % PMF failure conditions for a concrete gravity dam. The warning times were based on travel times from the HEC-RAS unsteady flow model minus the reaction time to notify the public. More detailed analysis will be preformed during DDR phase.

Table 6
Potential Loss of Life
Calculations for Dover Dam

	PAR	Avg. DV ft^2/s	Flood Severity	Fatality Rate	*Loss of Life	Warning Time (hrs)	**Loss of Life
Tuscarawas River (Below Dam to New Philadelphia)	25162	250	High	0.75	18871	1	49
Tuscarawas River to Muskingum River	12956	100	Medium	0.03	389	6	0
Tributaries of the Tuscarawas River	7872	85	Medium	0.03	236	12	0
Muskingum River to Ohio River	20260	100	Medium	0.03	608	32	0
Tributaries of the Muskingum River	4622	60	Medium	0.03	139	32	0

*Note: Fatality Rates Derived from Case Studies by the U.S. Department of The Interior A procedure for Estimating Loss of Life Caused by Dam Failure. (DSO-99-06)

**Note: However the warning time for such an event would be very high do to the fact that the U.S. Army Corps of Engineers monitoring of the dams during flood events are so extensive. The loss of life during a PMF event should be calculated by the following equations. It is assumed that during spillway flow warnings will be issued to the public.

$$\text{Deaths} = \frac{PAR}{((1 + 13.2277(PAR^{0.440})e^{[2.982(wt) - 3.790]}}$$

U.S. Department of the Interior “A procedure for Estimating Loss of Life Caused by Dam Failure”. (DSO-99-06)